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Campbell Essential Biology

SIXTH EDITION

Eric J. Simon • Jean L. Dickey • Kelly A. Hogan • Jane B. Reece

ALWAYS LEARNING

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Brief Contents

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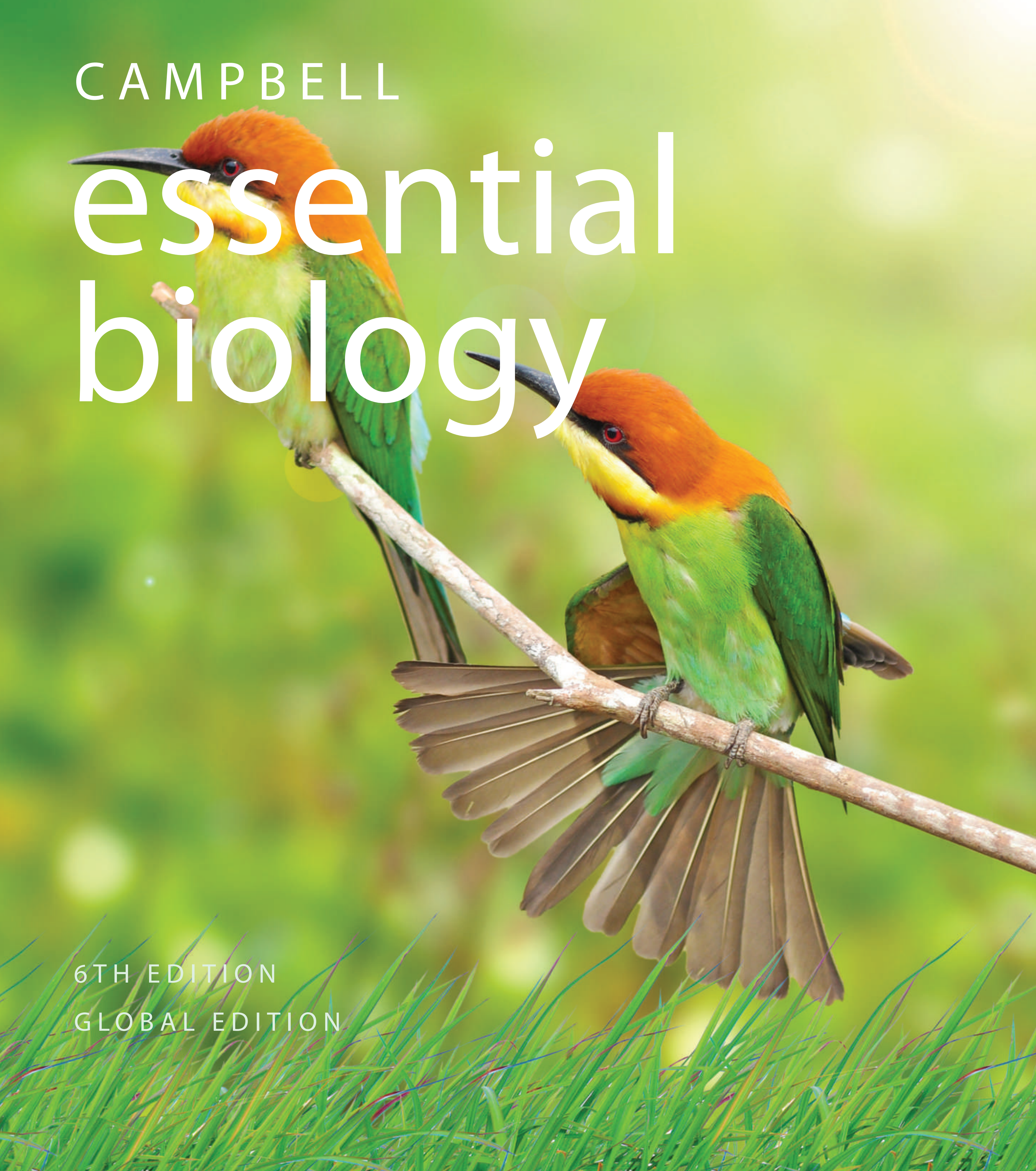

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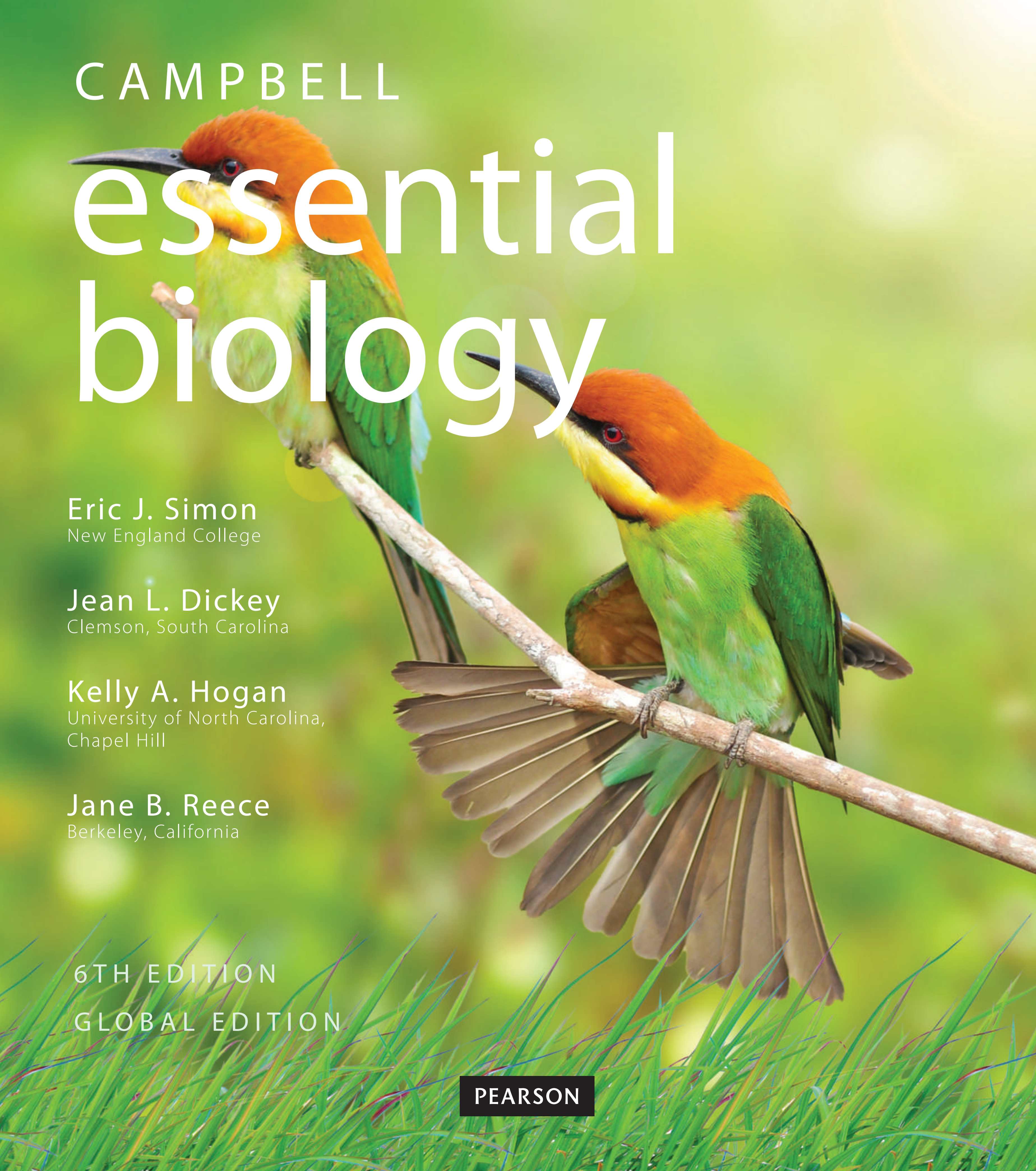

CAMPBELL

essential biology

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To Muriel, my wonderful mother, who has always supported my efforts with love, compassion, great empathy, and an unwavering belief in me

JEAN L. DICKEY

is Professor Emerita of Biological Sciences at Clemson University (Clemson, South Carolina). After receiving her B.S. in biology from Kent State University, she went on to earn a Ph.D. in ecology and evolution from Purdue University. In 1984, Dr. Dickey joined the faculty at Clemson, where she devoted her career to teaching biology to nonscience majors in a variety of courses. In addition to creating content-based instructional materials, she developed many activities to engage lecture and laboratory students in discussion, critical thinking, and writing, and implemented an investigative laboratory curriculum in general biology. Dr. Dickey is the author of *Laboratory Investigations for Biology*, 2nd Edition, and is a coauthor of *Campbell Biology: Concepts & Connections*, 8th Edition.

To my mother, who taught me to love learning, and to my daughters, Katherine and Jessie, the twin delights of my life

KELLY A. HOGAN

is a faculty member in the Department of Biology and the Director of Instructional Innovation at the University of North Carolina at Chapel Hill, teaching introductory biology and introductory genetics to science majors. Dr. Hogan teaches hundreds of students at a time, using active-learning methods that incorporate technology such as cell phones as clickers, online homework, and peer evaluation tools. Dr. Hogan received her B.S. in biology at the College of New Jersey and her Ph.D. in pathology at the University of North Carolina, Chapel Hill. Her research interests relate to how large classes can be more inclusive through evidence-based teaching methods and technology. She provides faculty development to other instructors through peer coaching, workshops, and mentoring. Dr. Hogan is the author of *Stem Cells and Cloning*, 2nd Edition, and is lead moderator of the *Instructor Exchange*, a site within MasteringBiology® for instructors to exchange classroom materials and ideas. She is also a coauthor of *Campbell Biology: Concepts & Connections*, 8th Edition.

To the good-looking boy I met in my introductory biology course many moons ago—and to our two children, Jake and Lexi, who are everyday reminders of what matters most in life

JANE B. REECE

has worked in biology publishing since 1978, when she joined the editorial staff of Benjamin Cummings. Her education includes an A.B. in biology from Harvard University (where she was initially a philosophy major), an M.S. in microbiology from Rutgers University, and a Ph.D. in bacteriology from the University of California, Berkeley. At UC Berkeley, and later as a postdoctoral fellow in genetics at Stanford University, her research focused on genetic recombination in bacteria. Dr. Reece taught biology at Middlesex County College (New Jersey) and Queensborough Community College (New York). During her 12 years as an editor at Benjamin Cummings, she played a major role in a number of successful textbooks. She is the lead author of *Campbell Biology*, 10th Edition, and *Campbell Biology: Concepts & Connections*, 8th Edition.

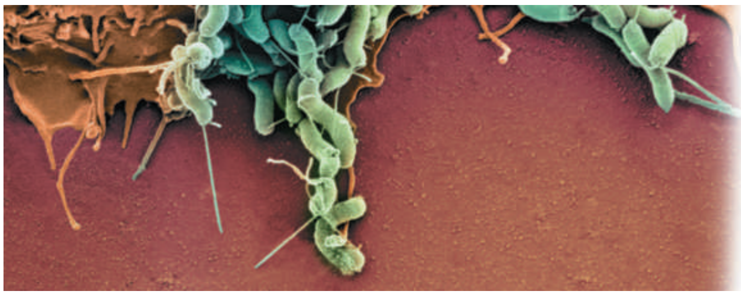
To my wonderful coauthors, who have made working on our books a pleasure

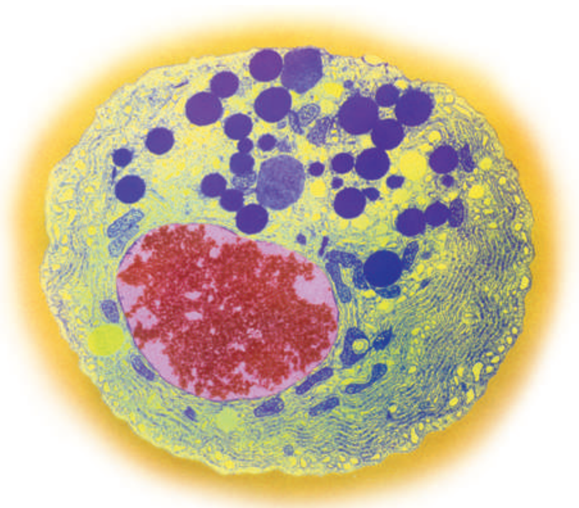
NEIL A. CAMPBELL

(1946–2004) combined the inquiring nature of a research scientist with the soul of a caring teacher. Over his 30 years of teaching introductory biology to both science majors and nonscience majors, many thousands of students had the opportunity to learn from him and be stimulated by his enthusiasm for the study of life. While he is greatly missed by his many friends in the biology community, his coauthors remain inspired by his visionary dedication to education and are committed to searching for ever-better ways to engage students in the wonders of biology.

Detailed Contents

UNIT 1 Cells



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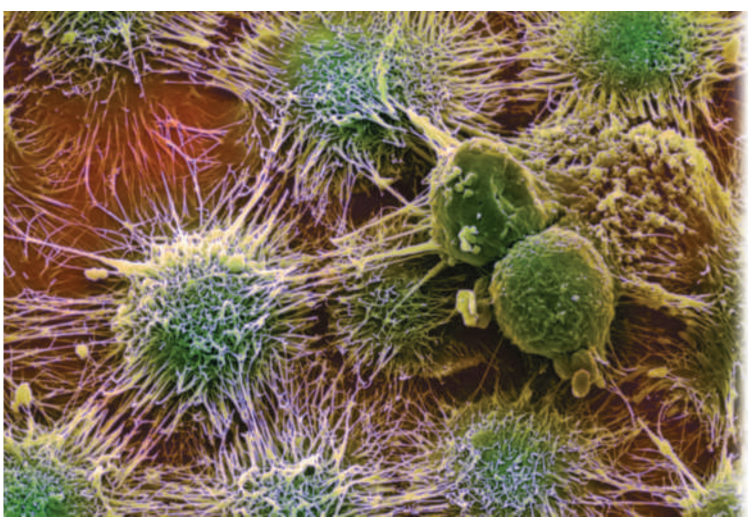
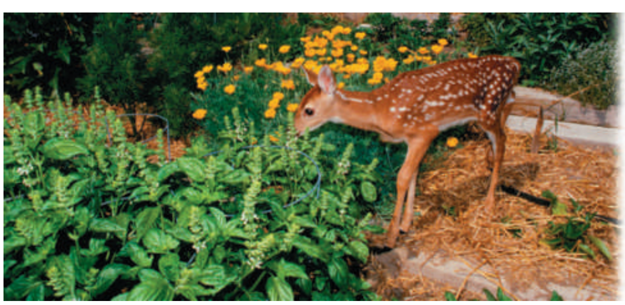



EVIDENCE BAG

UNIT 3 Evolution and Diversity



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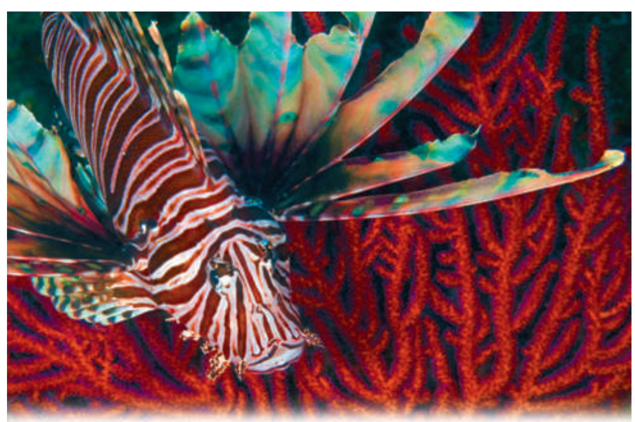
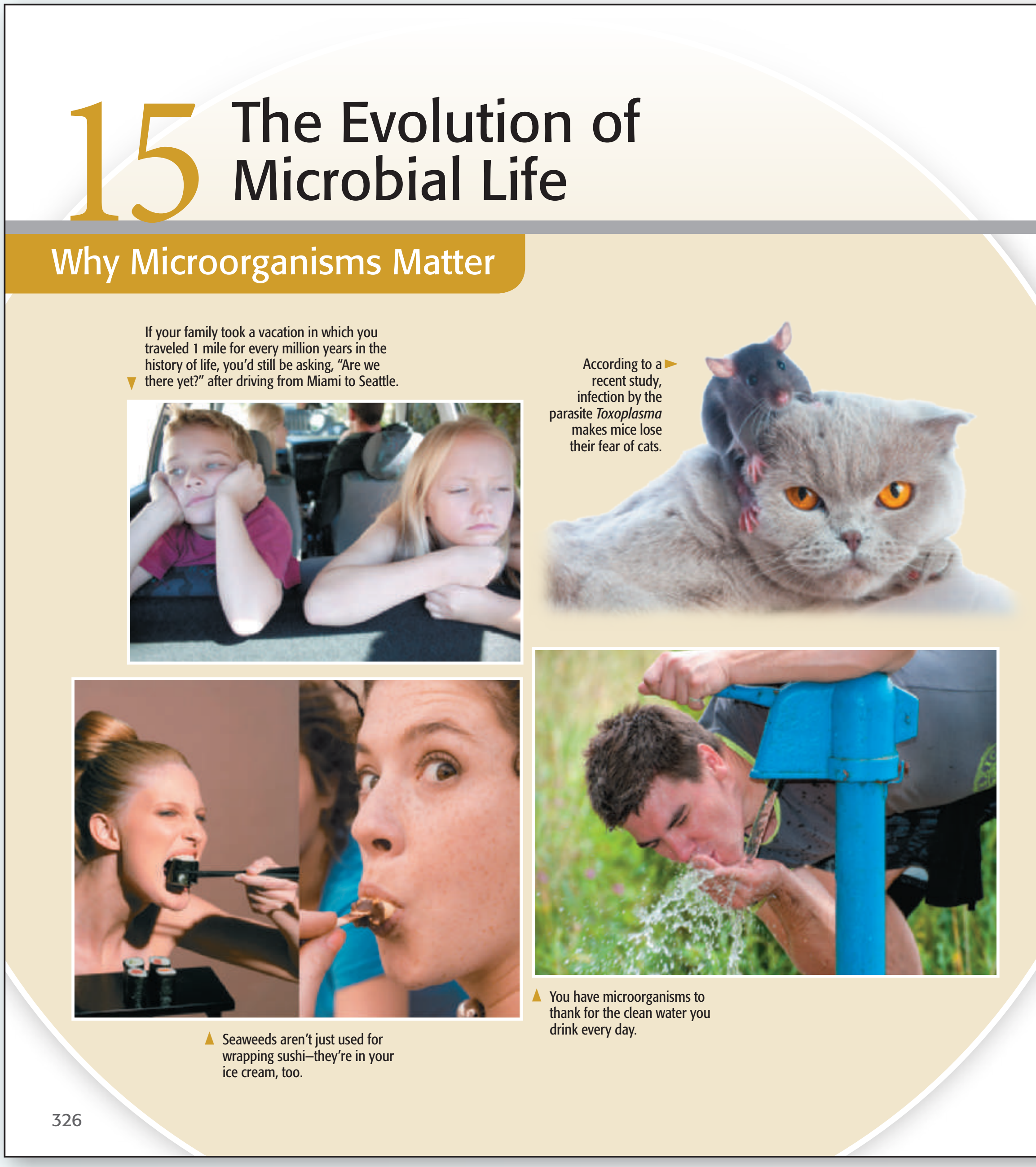


Discover Why Biology *Matters*

Campbell Essential Biology highlights how the concepts that you learn in your biology class are relevant to your everyday life.

- **NEW! Why Biology Matters Photo Essays** use dynamic photographs and intriguing scientific observations to introduce each chapter. Each scientific tidbit is revisited in the chapter.



15 The Evolution of Microbial Life

Why Microorganisms Matter

If your family took a vacation in which you traveled 1 mile for every million years in the history of life, you'd still be asking, "Are we there yet?" after driving from Miami to Seattle.

According to a recent study, infection by the parasite *Toxoplasma* makes mice lose their fear of cats.

Seaweeds aren't just used for wrapping sushi—they're in your ice cream, too.

You have microorganisms to thank for the clean water you drink every day.

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MasteringBiology®

NEW! Everyday Biology Videos briefly explore interesting and relevant biology topics that relate to concepts that students are learning in class. These 20 videos can be assigned in MasteringBiology with assessment questions.

- **UPDATED! Chapter Threads** weave a single compelling topic throughout the chapter. In Chapter 15, human microbiota are explored.

Human Microbiota BIOLOGY AND SOCIETY

Our Invisible Inhabitants

You probably know that your body contains trillions of individual cells, but did you know that they aren't all "you"? In fact, microorganisms residing in and on your body outnumber your own cells by 10 to 1. That means 100 trillion bacteria, archaea, and protists call your body home. Your skin, mouth, and nasal passages and your digestive and urogenital tracts are prime real estate for these microorganisms. Although each individual is so tiny that it would have to be magnified hundreds of times for you to see it, the weight of your microbial residents totals two to five pounds.

We acquire our microbial communities during the first two years of life, and they remain fairly stable thereafter. However, modern life is taking a toll on that stability. We alter the balance of these communities by taking antibiotics, purifying our water, sterilizing our food, attempting to germproof our surroundings, and scrubbing our skin and teeth. Scientists hypothesize that disrupting our microbial communities may increase our susceptibility to infectious diseases, predispose us to certain cancers, and contribute to conditions such as asthma and other allergies, irritable bowel syndrome, Crohn's disease, and autism. Researchers are even investigating whether having the wrong microbial community could make us fat. In addition, scientists are studying how our microbial communities have evolved over the course of human history. As you'll discover in the Evolution Connection section at the end of this chapter, for example, dietary changes invited decay-causing bacteria to make themselves at home on our teeth.

Colorized scanning electron micrograph of bacteria on a human tongue (14,500×).

Throughout this chapter, you will learn about the benefits and drawbacks of human-microbe interactions. You will also sample a bit of the remarkable diversity of prokaryotes and protists. This chapter is the first of three that explore the magnificent diversity of life. And so it is fitting that we begin with the prokaryotes, Earth's first life-form, and the protists, the bridge between unicellular eukaryotes and multicellular plants, fungi, and animals.

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Human Microbiota BIOLOGY AND SOCIETY

Biology and Society essays relate biology to your life and interests. This example discusses the microorganisms that live in your own body.

Human Microbiota THE PROCESS OF SCIENCE

Process of Science explorations give you real-world examples of how the scientific method is applied. Chapter 15 explores a recent investigation into the possible role of microbiota in obesity.

Human Microbiota EVOLUTION CONNECTION

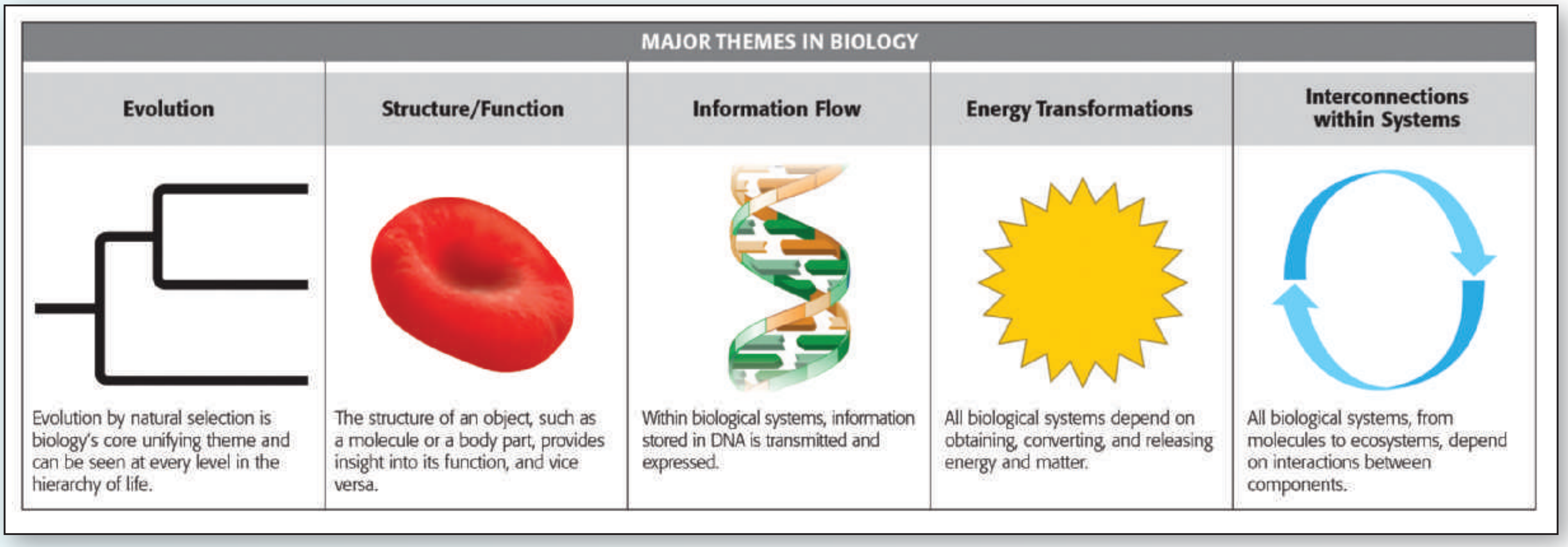
Evolution Connection essays conclude each chapter by demonstrating how the theme of evolution runs throughout all of biology. The example in Chapter 15 discusses how changes in the typical human diet over generations is linked to bacteria that cause tooth decay.

- **Additional updated Chapter Threads and essays** include radioactivity in Chapter 2, muscle performance in Chapter 6, and theft of used cooking oil for biofuel recycling in Chapter 7.

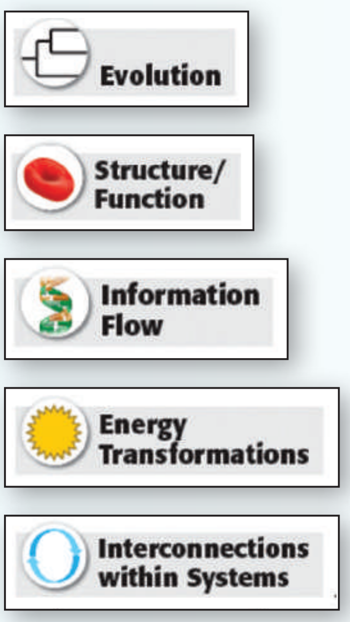
Identify "Big Picture" Themes

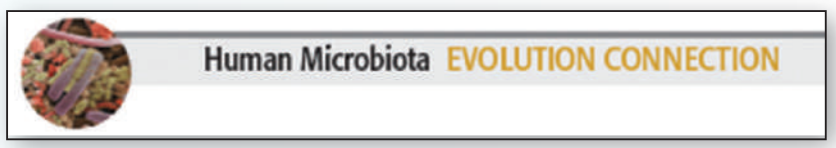
Examples of major themes in biology are highlighted throughout the text to help you see how overarching biology concepts are interconnected.

- **NEW! Important Themes in Biology** are introduced in Chapter 1 to underscore unifying principles that run throughout biology.



- These themes—Evolution, Structure/Function, Information Flow, Energy Transformations, and Interconnections within Systems—are **signaled with icons** throughout the text to help you notice the reoccurring examples of the major themes.





- The role of evolution throughout all of biology is further explored in depth at the end of each chapter in **Evolution Connection** discussions.

Recognize Analogies and Applications

Analogies and applications to everyday life make unfamiliar biology concepts easier to visualize and understand.

► **Figure 15.1 Some major episodes in the history of life.** On this 4,600-mile metaphorical road trip, each mile equals 1 million years in Earth's history.

If your family took a vacation in which you traveled 1 mile for every million years in the history of life, you'd still be asking, "Are we there yet?" after driving from Miami to Seattle.

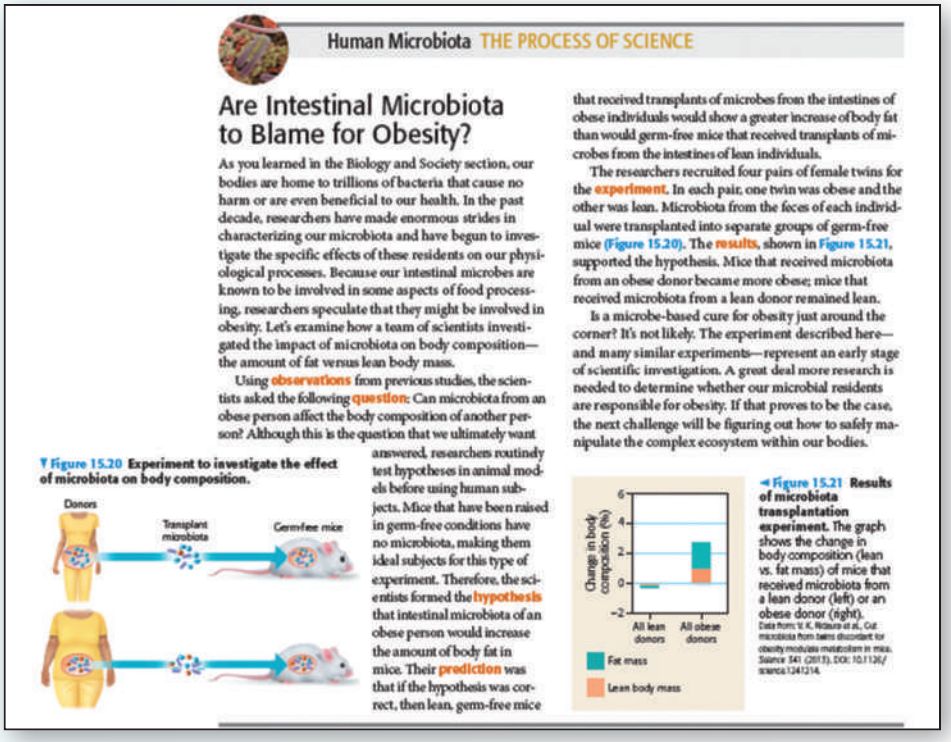
- **NEW analogies and applications** have been added throughout the prose and the illustrations, making it easier to learn and remember key concepts for the first time. Examples include:
  - comparing the significant differences between prokaryotic and eukaryotic cells to the differences between a bicycle and an SUV (Chapter 4)
  - comparing the process of DNA winding into chromosomes with the act of winding yarn into a skein (Chapter 10)
  - comparing a 4,600-mile road trip that describes the scale of biological evolution on Earth (Chapter 15)
  - comparing signal transduction to email communication (Chapter 27*)
  - comparing how dominoes relate to an action potential moving along an axon (Chapter 27*)

* Chapters 21–29 are included in the expanded version of the text that includes coverage of animal and plant anatomy and physiology.

Boost Your Scientific Literacy

A wide variety of exercises and assignments can help you move beyond memorization and think like a scientist.

- **UPDATED! Process of Science essays** appear in every chapter and walk through each step of the scientific method as it applies to a specific research question.



Human Microbiota THE PROCESS OF SCIENCE

Are Intestinal Microbiota to Blame for Obesity?

As you learned in the Biology and Society section, our bodies are home to trillions of bacteria that cause no harm or are even beneficial to our health. In the past decade, researchers have made enormous strides in characterizing our microbiota and have begun to investigate the specific effects of these residents on our physiological processes. Because our intestinal microbes are known to be involved in some aspects of food processing, researchers speculate that they might be involved in obesity. Let's examine how a team of scientists investigated the impact of microbiota on body composition—the amount of fat versus lean body mass.

Using **observations** from previous studies, the scientists asked the following **question**: Can microbiota from an obese person affect the body composition of another person? Although this is the question that we ultimately want answered, researchers routinely test hypotheses in animal models before using human subjects. Mice that have been raised in germ-free conditions have no microbiota, making them ideal subjects for this type of experiment. Therefore, the scientists formed the **hypothesis** that intestinal microbiota of an obese person would increase the amount of body fat in mice. Their **prediction** was that if the hypothesis was correct, then lean, germ-free mice that received transplants of microbes from the intestines of obese individuals would show a greater increase of body fat than would germ-free mice that received transplants of microbes from the intestines of lean individuals.

The researchers recruited four pairs of female twins for the **experiment**. In each pair, one twin was obese and the other was lean. Microbiota from the feces of each individual were transplanted into separate groups of germ-free mice (Figure 15.20). The **results**, shown in Figure 15.21, supported the hypothesis. Mice that received microbiota from an obese donor became more obese; mice that received microbiota from a lean donor remained lean.

Is a microbe-based cure for obesity just around the corner? It's not likely. The experiment described here—and many similar experiments—represent an early stage of scientific investigation. A great deal more research is needed to determine whether our microbial residents are responsible for obesity. If that proves to be the case, the next challenge will be figuring out how to safely manipulate the complex ecosystem within our bodies.

▼ Figure 15.20 Experiment to investigate the effect of microbiota on body composition.

◄ Figure 15.21 Results of microbiota transplantation experiment. The graph shows the change in body composition (lean vs. fat mass) of mice that received microbiota from a lean donor (left) or an obese donor (right).
Data from: V. K. Ridaura et al., Gut microbiota from twins discordant for obesity modulate metabolism in mice. Science 341 (2013). DOI: 10.1126/science.1241214.

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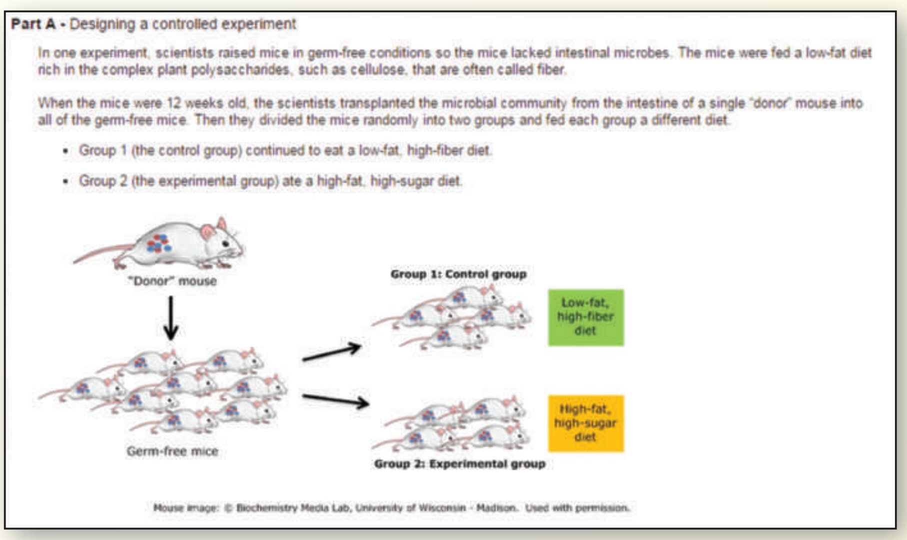


Part A - Designing a controlled experiment

In one experiment, scientists raised mice in germ-free conditions so the mice lacked intestinal microbes. The mice were fed a low-fat diet rich in the complex plant polysaccharides, such as cellulose, that are often called fiber.

When the mice were 12 weeks old, the scientists transplanted the microbial community from the intestine of a single "donor" mouse into all of the germ-free mice. Then they divided the mice randomly into two groups and fed each group a different diet.

- Group 1 (the control group) continued to eat a low-fat, high-fiber diet.
- Group 2 (the experimental group) ate a high-fat, high-sugar diet.

Mouse image: © Biochemistry Media Lab, University of Wisconsin - Madison. Used with permission.

- **NEW! Scientific Thinking Activities** are designed to help you develop an understanding of how scientific research is conducted.

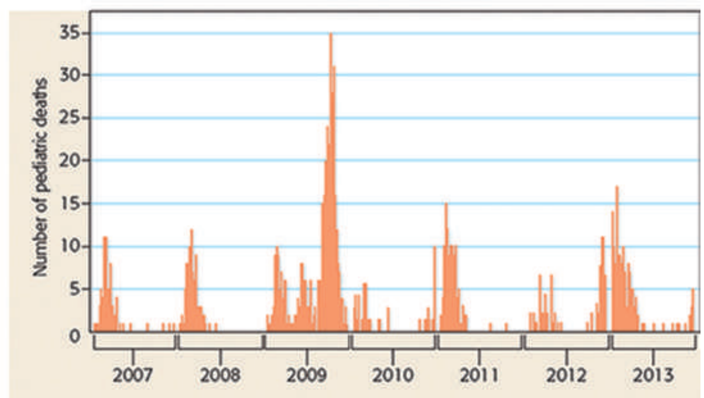
- **NEW! Evaluating Science in the Media Activities** challenge you to recognize validity, bias, purpose, and authority in everyday sources of information.

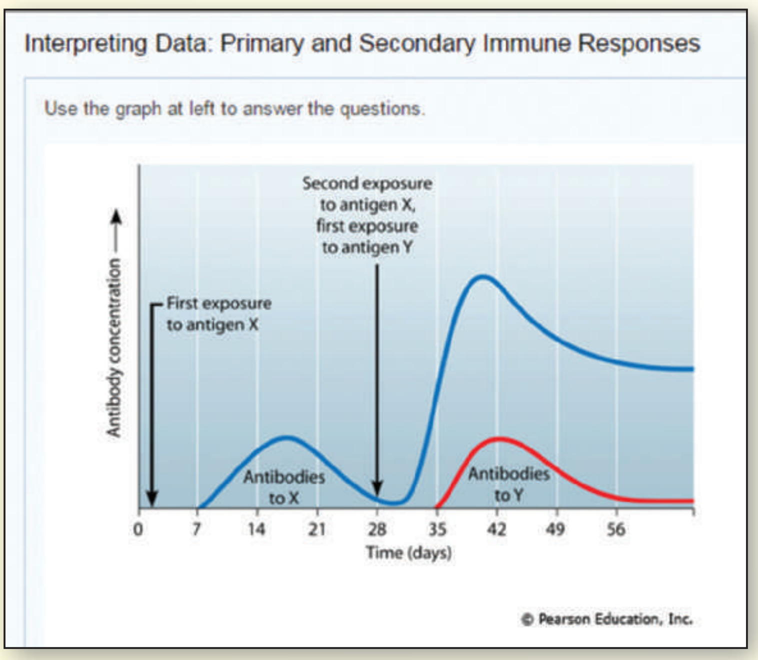
Learn to Interpret Data

Data interpretation is important for understanding biology and for making many important decisions in everyday life. Exercises in the text and online will help you develop this important skill.

- **NEW! Interpreting Data end-of-chapter questions** help you learn to use quantitative material by analyzing graphs and data. This example from Chapter 10 invites you to examine historical data of flu mortality. Other examples include:
  - Chapter 13: Learn how markings on snail shells affect predation rates in an environment
  - Chapter 15: Calculate how quickly bacteria can multiply on unrefrigerated food

14. Interpreting Data The graph below summarizes the number of children who died of all strains of flu from 2007 until 2013. Each bar represents the number of child deaths occurring in one week. Why does the graph have the shape it does, with a series of peaks and valleys? Looking over the Biology and Society section at the start of the chapter, why does the graph reach its highest points near the middle? Based on these data, when does flu season begin and end in a typical year?





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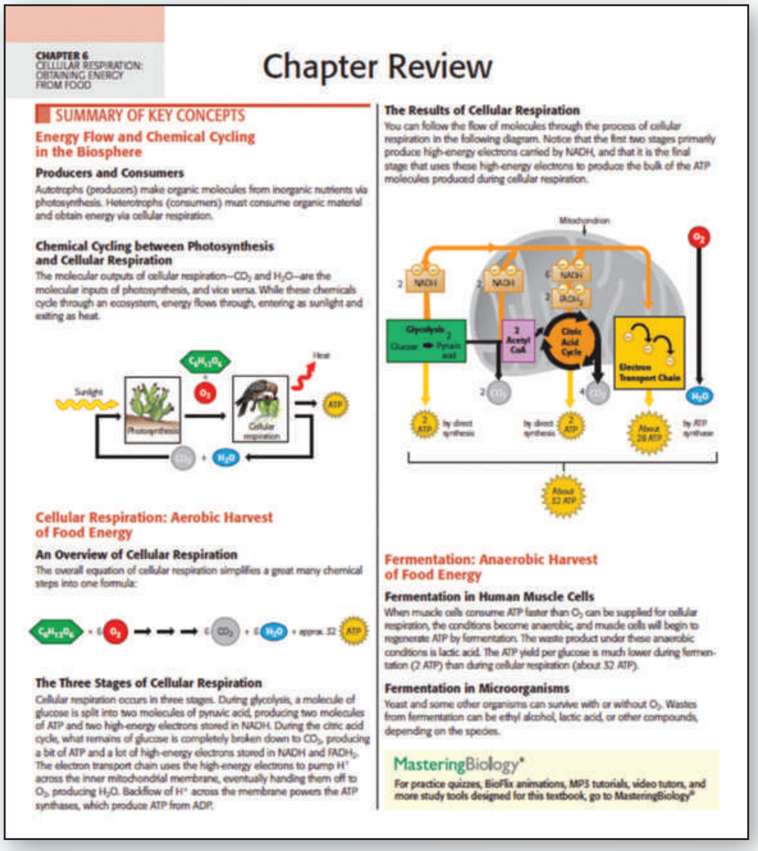
NEW! Interpreting Data Activities help you build and practice data analysis skills.

Maximize Your Study Time

Campbell Essential Biology and the **MasteringBiology** homework, tutorial, and assessment program work hand-in-hand to help students succeed in introductory biology.

- **The Chapter Review** offers a built-in study guide that combines words with images to help you organize the key concepts. The unique figures in the Chapter Review synthesize information from the corresponding chapter, which helps you study more efficiently.


CHAPTER 6
CELLULAR RESPIRATION: OBTAINING ENERGY FROM FOOD

Chapter Review

SUMMARY OF KEY CONCEPTS

Energy Flow and Chemical Cycling in the Biosphere

Producers and Consumers

Autotrophs (producers) make organic molecules from inorganic nutrients via photosynthesis. Heterotrophs (consumers) must consume organic material and obtain energy via cellular respiration.

Chemical Cycling between Photosynthesis and Cellular Respiration

The molecular outputs of cellular respiration—CO_2 and H_2O—are the molecular inputs of photosynthesis, and vice versa. While these chemicals cycle through an ecosystem, energy flows through, entering as sunlight and exiting as heat.

Cellular Respiration: Aerobic Harvest of Food Energy

An Overview of Cellular Respiration

The overall equation of cellular respiration simplifies a great many chemical steps into one formula:

$C_6H_{12}O_6$ + 6 O_2 → → → 6 CO_2 + 6 H_2O + approx. 32 ATP

The Three Stages of Cellular Respiration

Cellular respiration occurs in three stages. During glycolysis, a molecule of glucose is split into two molecules of pyruvic acid, producing two molecules of ATP and two high-energy electrons stored in NADH. During the citric acid cycle, what remains of glucose is completely broken down to CO_2, producing a bit of ATP and a lot of high-energy electrons stored in NADH and $FADH_2$. The electron transport chain uses the high-energy electrons to pump H^+ across the inner mitochondrial membrane, eventually handing them off to O_2, producing H_2O. Backflow of H^+ across the membrane powers the ATP synthases, which produce ATP from ADP.

The Results of Cellular Respiration

You can follow the flow of molecules through the process of cellular respiration in the following diagram. Notice that the first two stages primarily produce high-energy electrons carried by NADH, and that it is the final stage that uses these high-energy electrons to produce the bulk of the ATP molecules produced during cellular respiration.

Fermentation: Anaerobic Harvest of Food Energy

Fermentation in Human Muscle Cells

When muscle cells consume ATP faster than O_2 can be supplied for cellular respiration, the conditions become anaerobic, and muscle cells will begin to regenerate ATP by fermentation. The waste product under these anaerobic conditions is lactic acid. The ATP yield per glucose is much lower during fermentation (2 ATP) than during cellular respiration (about 32 ATP).

Fermentation in Microorganisms

Yeast and some other organisms can survive with or without O_2. Wastes from fermentation can be ethyl alcohol, lactic acid, or other compounds, depending on the species.

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For practice quizzes, BioFlix animations, MP3 tutorials, video tutors, and more study tools designed for this textbook, go to MasteringBiology®

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MasteringBiology provides a wide range of activities and study tools to match your learning style, including BioFlix animations, MP3 audio tutorials, interactive practice quizzes, and more. Your instructor can assign activities for extra practice to monitor your progress in the course.

NEW! Essential Biology videos introduce you to key concepts and vocabulary, and are narrated by authors Eric Simon and Kelly Hogan. Topics include the **Scientific Method**, **Molecules of Life**, **DNA Replication**, **Mechanisms of Evolution**, **Ecological Principles**, and more.